XXII. *On the* Georgian *Planet and its Satellites.* *By* William Herſchel, *LL.D. F. R. S.*

Read May 22, 1788.

IN a Paper, containing an account of the diſcovery of two ſatellites revolving round the Georgian planet, I have given the periodical times of theſe ſatellites in a general way, and added that their orbits made a conſiderable angle with the ecliptic. It is hardly neceſſary to mention, that it requires a much longer ſeries of obſervations, to ſettle the mean motions of ſecondary planets with accuracy, than I can hitherto have had an opportunity of making; but ſince it will be ſome ſatiſfaction to aſtronomers to be acquainted with ſeveral of the moſt intereſting particulars, as far as they can as yet be aſcertained, I ſhall communicate the reſult of my paſt obſervations; and believe that, conſidering the difficulty of meaſuring objects which require the utmoſt attention even to be at all perceived, the elements here delivered will be found to be full as accurate as we can at this time expect to have them ſettled.

The moſt convenient way of determining the revolution of a ſatellite round its primary planet, which is that of obſerving its eclipſes, cannot now be uſed with the Georgian ſatellites, as will be ſhewn when I come to give the poſition of their orbits; and as to taking their ſituations in many ſucceſſive oppoſitions of the planet, which is likewiſe another very eligible method, that muſt of courſe remain to be done at pro-

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per opportunities. The only way then left, was to take the ſituations of theſe ſatellites, in any place where I could aſcertain them with ſome degree of preciſion, and to reduce them afterwards by computation to ſuch other ſituations as were required for my purpoſe.

In January, February, and March, 1787, the poſitions were determined by cauſing the planet to paſs along a wire, and eſtimating the angle a ſatellite made with this wire, by a high magnifying power; but then I could only uſe ſuch of theſe ſituations where the ſatellite happened to be either directly in the parallel of declination, or in the meridian of the planet; or where, at leaſt, it did not deviate above a few degrees from either of them; as it would not have been ſafe to truſt to more diſtant eſtimations. In October I had improved my apparatus ſo far as to meaſure the poſitions by the ſame angular micrometer with which I have formerly determined the relative poſitions of double ſtars *.

In computing the periods of the ſatellites I have contented myſelf with ſynodical appearances, as the poſition of their orbits, at the time when the ſituations were taken from which theſe periods are deduced, was not ſufficiently known to attempt a very accurate ſidereal calculation. By ſix combinations of poſitions at a diſtance of 7, 8, and 9 months of time, it appears that the firſt ſatellite performs a ſynodical revolution round its primary planet in 8 days 17 hours 1 minute and 19,3 ſeconds. The period of the ſecond ſatellite deduced likewiſe from four ſuch combinations, at the ſame diſtance of time, is 13 days 11 hours 5 minutes and 1,5 ſeconds. The

* For a deſcription of this inſtrument, ſee Phil. Tranſ. Vol. LXXI. p. 500. and Vol. LXXV. p. 46.

combinations of which the above quantities are a mean do not differ much among themſelves; it may therefore be expected that theſe periods will come very near the truth; and, indeed, I have for many months paſt been uſed to calculate the places of the ſatellites by them, and have hitherto always found them in the ſituations where theſe computations gave me reaſon to expect to ſee them.

The epochæ, from which aſtronomers may calculate the poſitions of theſe ſatellites, are October 19, 1787; for the firſt 19 h. 11′ 28″; and for the ſecond 17 h. 22′ 40″. They were at thoſe times 76° 43′ north-following the planet; which, as will be ſhewn in the ſequel, is the place of the greateſt elongation of the ſecond ſatellite; where, conſequently, its real angular ſituation is the ſame as the apparent one. And I have brought the firſt ſatellite to the ſame place, as hitherto there has not been time to diſcriminate the ſituation of its orbit from that of the ſecond.

The next thing to be determined in the elements of theſe ſatellites is their diſtance from the planet; and as we know that, when the periodical times are given, it is ſufficient to have the diſtance of one ſatellite in order to find that of any other, I confined my attention to the diſcovery of the diſtance of the ſecond. As ſoon as I attempted meaſures, it appeared, that the orbit of this ſatellite was ſeemingly elliptical; it became therefore neceſſary, in order to aſcertain its greateſt elongation, to repeat theſe meaſures in all convenient ſituations; the reſult of which was, that on the 18th of March, at 8 h. 2′ 50″, I found the ſatellite at the diſtance of 46″,46; this being the largeſt of all the meaſures I have had an opportunity of taking. Hence, by computation, it appears, that the

ſatellite's greateſt viſible elongation from its planet, at the mean diſtance of the Georgium ſidus from the earth, will be 44″,23.

It ought to be mentioned, that in the reduction of this meaſure I have uſed MAYER's tables for the ſun, and the tables publiſhed in the *Connoiſſance des Temps* of the year 1787, reduced to the time of Greenwich, for the Georgian planet.

Very poſſibly this diſtance might not be taken exactly at the time when the ſatellite happened to be at the vertex of the tranſverſe axis of its apparently elliptical orbit; but, from other meaſurements, we have reaſon to conclude, that it could not be far from that point. For inſtance, the 9th of November, at 15 h. 56′ 15″, by a mean of four good meaſures, the ſatellite was 44″,89 from the planet; which, by calculation, reduced to the ſame diſtance of the Georgian ſidus from the earth as the former, gives 41″,33. And likewiſe, the 19th of March, at 7 h. 45′ 59″, the diſtance meaſured 44″,24; which, computed as before, gives 42″,15. Now, we find, when the places are calculated in which the ſatellite happened to be at the times when theſe two meaſures were taken, that they fall on different ſides of the former meaſure, and alſo on oppoſite parts of the ſatellite's orbit; but that nevertheleſs they agree ſufficiently well with the poſition of the tranſverſe axis which we have adopted in the ſequel.

Admitting, therefore, at preſent, that the ſatellite moves in a circular orbit about its planet, we cannot be much out in taking the calculated quantity of 44″,23 for the true meaſure of its diſtance. And, having aſcertained this point, we calculate, by the law of KEPLER, and the aſſigned period of the firſt ſatellite, that its diſtance from the planet muſt be 33″,09. I ought however to remark, that, in this computation, a true ſidereal period ſhould have been uſed; but, as that cannot as

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yet be had, the trifling inaccuracy thence arifing may well be excufed, till, at fome future opportunity, we may be permitted to repeat thefe calculations in a more rigorous manner.

As we are now upon the fubject of fuch parts of the theory of planets as may be determined by calculation, it will not be amifs to fee how the quantity of matter and denfity of our new planet will ftand, when compared with the tables that have been given of the fame in the other planets; and in order to this, let us admit the following *data* as a foundation for our computation.

The parallax of the fun 8″,63.

The parallax of the moon 57′ 11″.

Its fidereal revolution round the earth 27 d. 7 h. 43′ 11″,6.

The mean diftance of the Georgian planet from the fun 19,0818.

The mean diftance of its fecond fatellite from the planet 44″,23.

The periodical time of this fatellite 13 h. 11 d. 5′ 1″,5.

Hence we find, that a fpectator, removed to the mean diftance of the Georgian planet from the earth, would fee the radius of the moon's orbit under an angle of 27″,1866; and if 1, *d*, *t*, reprefent the quantity of matter in the earth, the diftance of the moon, and its periodical time; M, D, T, be made to ftand for the fame things in our new planet and its fecond fatellite, we obtain, by known principles, $M = \frac{t^2 D^3}{T^2 d^3}$. And, confequently, the quantity of matter in the Georgian planet is to that contained in the earth as 17,740612 to 1.

In order to caculate the denfity, I compare the mean of the four bright meafures of the planet's diameter 3,″7975 to the

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mean of the two dark ones 4″,295; as they are given in my Paper on the diameter and magnitude of the Georgium ſidus, printed in Volume LXXIII. of the Philoſophical Tranſactions, p. 9. 11, 12, 13. Whence we obtain another mean diameter 4″,04625; which is probably the moſt accurate of any that we have hitherto aſcertained. And let us ſuppoſe this meaſure to belong to the ſituations of the earth and of the new planet as they were at 10 o'clock, the 25th of October, 1782; which is about the middle of the ſeveral times when thoſe meaſures from which this is deduced were taken. Then, by the tables already referred to, we compute the diſtance of the two planets from the ſun and the angle of commutation; whence, by trigonometry, we find the diſtance of our new planet from the earth for the ſuppoſed 25th of October; and thence deduce its mean diameter, which is 3″,90554. This, when brought to what it would appear if it were ſeen from the ſun at the earth's mean diſtance, gives 1′ 14″,5246; which, compared with 17″,26, the earth's mean diameter, is as 4,31769 to 1. The Georgium ſidus, therefore, in bulk, is 80,49256 times as large as the earth; and conſequently its denſity leſs than that of the latter in the ratio of ,220401 to 1.

To theſe particulars, though many of them may be of no other uſe than merely to ſatisfy our curioſity, we may alſo add, that the force of gravity, on this planet's ſurface, is ſuch as will cauſe an heavy body to fall through 18,67308 feet in one ſecond of time.

It remains now only, in order to complete our general idea of the Georgian planet, to inveſtigate the ſituation of the orbits of its ſatellites. I have before remarked, that when I came to examine the diſtance of the ſecond, I perceived immediately that its orbit appeared conſiderably elliptical. This induced

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me to attempt as many meaſures as poſſible, that I might be enabled to come at the proportion of the axes of the apparent ellipſis; and thence argue its ſituation. But here I met with difficulties that were indeed almoſt inſurmountable. The uncommon faintneſs of the ſatellites; the ſmallneſs of the angles to be meaſured with micrometers which required light enough to ſee the wires; the unwieldy ſize of the inſtrument, which, though very manageable, ſtill demanded aſſiſtant hands for its movements, and conſequently took away a great ſhare of my own directing power, a thing ſo neceſſary in delicate obſervations; the high magnifiers I was obliged to uſe by way of rendering the ſpaces and angles to be meaſured more conſpicuous; in ſhort, every circumſtance ſeemed to conſpire to make the caſe a deſperate one. Add to this, that no meaſure could poſſibly ſucceed which had not the moſt beautiful ſky in its favour; and we may eaſily judge how ſcarce the opportunities of taking ſuch meaſures muſt be in the variable climate of this iſland. As far then as a ſmall number of ſelect meaſures will permit, which, out of about twenty-one that were taken, amounts only to five, I ſhall enter into our preſent ſubject of the poſition of the ſecond ſatellite's orbit.

The following table contains in the firſt column the correct mean time when the meaſures were taken. The ſecond gives the quantity of theſe meaſures. In the third column are the ſame meaſures reduced to the mean diſtance of the Georgian planet from the earth. The fourth contains the calculated poſitions of the ſatellite as it would have appeared to be ſituated if it had moved in a circular orbit at rectangles to the viſual ray; and the degrees are numbered from the firſt obſervation ſuppoſed to have been at zero, and are carried round the circle from right to left.

March

	D.	H.	′	″	″	″	°	′
March	18	8	2	50	46,46	44,23	0	0
	19	7	47	59	44,24	42,15	26	28
	20	7	44	8	40,23	38,37	53	8
April	11	9	18	27	35,32	34,35	283	13
Nov.	9	15	56	15	44,89	42,88	199	59

In the uſe of this table I ſhall partly content myſelf with the conſtruction of a figure, and only apply calculation to the moſt material circumſtances. By the third column we ſee that 44″,23 is the greateſt, and 34″,35 the leaſt, diſtance of the ſatellite. Let therefore an ellipſis be drawn Tab. V. fig. 1. having the tranſverſe and conjugate diameters *cp* and *cv*, in the proportion of the above-mentioned meaſures. About the center *c*, with the radius *cp*, deſcribe the circle PSFN; and ſet off the points March 18, 19, 20. April 11. and Nov. 9. according to the tabular order of degrees, beginning at *p*, the ſuppoſed zero. From theſe points to the tranſverſe draw the ordinates March 19 *s*, 20 *t*, April 11 *x*, Nov. 9 *y*. Then, if the ſatellite moved in a circular orbit at rectangles to the viſual ray, we ſhould have ſeen it at the time given in the table, as the points are placed in the circumference of our circle; but, ſuppoſing the plane of the orbit inclined to the viſual ray, theſe points will be projected in the direction of the ordinates; and, falling on the places *p n m r o*, will form the ellipſis we have delineated. Now, on comparing the tabular meaſures of the third column with the diſtances of *p n m r* and *o* from the center *c*, we find, that they agree full as well as we could expect; and thus, as far as a few obſervations can do, theſe meaſures eſtabliſh the truth of the above hypotheſis.

That we may have a point in our ellipſis from which to depart, I ſhall have recourſe to two meaſures of poſitions. The firſt was taken October 14 d. 16 h. 28′ 42″, when the ſatellite was 66° 3′ ſouth-following the planet. In fig. 2. let *qmv* be a portion of an ellipſis, conſtructed on the ſemi-tranſverſe *cq*, and ſemi-conjugate *cv*, taken as 44,23 to 34,35; *q*MF an arch of a circle, deſcribed with the radius *cq* about the center *c*; *m* the ſituation of the ſatellite in its elliptical orbit, the 14th of October; A its apparent, and M its real place in the circle; F*c* the parallel of the planet. Then we ſhall have, by calculating from the known period, the arch *q*M 45° 17′; and FA, by obſervation, 66° 3′. But from the nature of the ellipſis, as V*c* is to *vc* ſo is M*n* (the tangent of the angle *qc*M to the radius *cn*) to *mn* (the tangent of the angle *qc*A to the ſame radius). Hence *qc*A is found 38° 7′; and therefore A*c*M 7° 10′. That is, when the angle of poſition was taken, the ſatellite appeared to be 7° 10′ leſs advanced in its orbit than it ſhould have done, owing to its motion in an orbit whoſe plane is inclined to the viſual ray. The meaſure therefore corrected, or rather reduced to the circle, inſtead of 66° 3′, will be 58° 53′ ſouth-following; to which, adding the calculated arch *q*A, and from the ſum deducting 90°, we have the poſition *qc*S with the meridian 14° 10′ on the ſouth-preceding ſide. In the ſame manner I proceed with the ſecond meaſure taken October 20 d. 16 h. 7′ 34″; when the ſatellite appeared to be 82° 12′ north-preceding the planet. Here the arch *q*M is 25° 21′, A*c*M 5° 9′; and the meaſure corrected 77° 3′ north-preceding, which gives the inclination of the axis to the meridian 12° 24′ on the north-following ſide. I have no reaſon to prefer either of the meaſures, and therefore take a mean of both, which is 13° 17′ from ſouth-preceding to

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north-following the meridian, as probably neareſt the truth; and this poſition of the axis we may ſuppoſe to belong to a time which is about the mean of thoſe from which it has been deduced; or October, 17 d. 16 h.

We are, in the next place, to find the angle which the plane of the meridian made at that time with the plane of the orbit of the Georgian planet. To this end we calculate its longitude and latitude for the given time. Then, in fig. 3. where ♋ NE is part of the ſolſtitial colure, *nc* a portion of the orbit, and ♋ *s* of the ecliptic; there is given the arch NE, 23° 28′; E*c*, 89° 27′ 49″,2 the complement of the planet's latitude; and the angle ♋ E*s*, 27° 0′ 52″,2, or planet's diſtance from Cancer. By theſe we find the angle E*c*N between the circle of latitude N*c* and the meridian E*c* 11° 11′ 41″. Now, let *c*, in fig. 4. be the place of the Georgian planet, and G☊*c* a part of its orbit; *e*☊*s* part of the ecliptic; N*c* the meridian; ☊ the place of the planet's aſcending node; *pcq* the poſition of the axis of the apparently elliptical orbit of the ſecond ſatellite; E*c*N the angle of poſition of the Georgium ſidus. Then, by calculation, for the above-mentioned day we have ☊*c*, the planet's diſtance from the node on its orbit 44° 8′ 17″; *c*☊*s* the inclination of its orbit to the ecliptic 46′ 13″; and ☊*sc* a right-angle; whence E*c*☊ 90° 33′ 10″,1 the ſupplement of the angle *sc*☊ is found; from which, taking the angle of poſition N*c*E, before obtained, we have the remaining angle, N*c*G, 79° 21′ 29″,1; or inclination of the planet's orbit to the plane of the meridian, which was required.

From the proportion of the tranſverſe *cp*, fig. 1. to the conjugate *cv*, we calculate the angle *vpc*, which may be either acute or obtuſe. For here I muſt take notice, that obſervations cannot immediately determine whether the ſatellite, in paſſing from *p* through *n m v* to *q*, be in the fartheſt or neareſt part of

its orbit; as we ſhall preſently ſhew that this orbit is not in a ſituation to permit the ſatellite to ſuffer either eclipſes or occultations for ſome time to come. The angle *vpc*, therefore, if the arch *pvq* be turned towards us will be 129° 2′ 46″,5; but, if directed the contrary way, 50° 57′ 13″,5. There is one circumſtance which will bring on a diſcovery of this particular, without waiting for eclipſes; for if the apparent ellipſis of the ſatellite's orbit ſhould contract in a year or two, we may conclude this arch to lie towards the ſun; if, on the contrary, it opens, we ſhall know that the ſatellite has paſſed through one of its nodes about eight or nine years ago; and that, therefore, we muſt not expect to ſee it eclipſed for more than thirty years to come.

Now, having already determined the poſition of the axis *pc* with reſpect to the meridian, by adding the angles N*cp* and N*c*G, fig. 4. we obtain *pcn*, 92° 38′ 29″,1; and having alſo now calculated the ambiguous angle *npc*, we may reſolve the quadrantal triangle *pcn*, in which the angle *cnp* gives the inclination of the orbit of the ſatellite to the orbit of its planet, which will be 99° 39′ 48″,9, if the ſatellite be approaching to its aſcending node; but 80° 20′ 11″,1, if it be lately paſt the deſcending one.

In the ſame triangle we find the ſide *nc*, which is either 50° 59′ 0″,8 or 129° 0′ 59″,2; and taking theſe quantities, increaſed by ſix ſigns, from the longitude of the planet in its orbit, gives the place of the ſatellite's aſcending node upon the orbit of the planet, either 8 s. 6° 2′ 0″,3, if the preceding arch of the orbit *pmn*, be concave towards the ſun; or 5 s. 18° 0′ 1″,9, if it be convex.

Theſe elements obtained, we reduce them to the ecliptic by reſolving the triangle ☊*nm*, in which we have *m*☊*n*, 46′ 13″;

4 *n*☊

$n ☊$ the diſtance of the aſcending node of the ſatellite from the deſcending node of the planet $6° 50' 43'',8$ or $84° 52' 42'',1$; and $☊ n m$, the inclination of the ſatellite's orbit to that of its planet $99° 39' 49'',9$ anſwering to the former, or $80° 20' 11'',1$ to the latter. In conſequence of this reſolution, we have the place of the aſcending node of the ſatellite upon the ecliptic, $\left\{\begin{matrix} 5\text{ s. } 18° & 0' & 3'',9 \\ 8 \quad\quad 6 & 2 & 2\ ,3 \end{matrix}\right\}$, and its inclination to the ſame $\left\{\begin{matrix} 99° & 43' & 53'',3 \\ 81 & 6 & 4\ ,4 \end{matrix}\right\}$. The orbit being ſituated ſo, that when the planet will be in the aſcending node of this ſatellite, which will happen about the year $\left\{\begin{matrix} 1799 \\ 1818 \end{matrix}\right\}$, the northern half of it will be turned towards the $\left\{\begin{matrix} \text{Eaſt} \\ \text{Weſt} \end{matrix}\right\}$ at the time of its meridian paſſage.

In juſtice to the foregoing calculations I ſhould add, that the reſult of them muſt be conſiderably affected by any ſmall alteration in the meaſures upon which they are founded; the general theory, however, will certainly ſtand good, and a greater perfection in particulars could not have been obtained, unleſs I had waited ſome years, at leaſt, in order to multiply good obſervations. But with objects that are out of the reach of common teleſcopes, and which therefore cannot be much attended to, even by our moſt aſſiduous aſtronomers, a general theory will perhaps nearly anſwer all the ends that may be required of it.

The meaſures of the diſtances were taken by a good parallel-wire micrometer, contrived ſo that one of the wires, which is moveable, can paſs over the other; by which means central meaſures may be obtained with more accuracy than by allowing for

for the thicknefs of the wires, the afcertaining of which is liable to fome difficulties in other conftructions; but here, as we can note the divifions on the firft appearance of light at either fide of the fixed wire, when the moveable one paffes over it backwards and forwards, we may very conveniently determine that part of the fcale to which the zero ought to anfwer in central meafures. The value of the fcale was afcertained by the tranfit of ftars over the two wires opened to a certain number of divifions, and a chronometer beating five times in two feconds of mean time; and in a number of feveral fets of experiments, the mean of each feldom differed fo much as the 500dth part of a fecond of fpace for each divifion, and thefe are large enough to be fub-divided and read off, with good exactnefs to tenths; and yet the fpace anfwering to each part amounts only to 282 millefimals of a fecond. The meafures of the diftances alfo were as often repeated as the opportunities would permit, and a mean of them has been ufed.

The light of the fatellites of the Georgian planet is, as we may well expect, on account of their great diftance, uncommonly faint. The fecond is the brighteft of the two, but the difference is not confiderable; befides, we muft allow for the effect of the light of the planet, which is pretty ftrong within the fmall diftances at which they are revolving. I have feen fmall fixed ftars, as near the planets as the fatellites, and with no greater light, which, on removal of the planet, fhone with a confiderable luftre, fuch as I had by no means expected of them. A fatellite of Jupiter, removed to the diftance of the Georgian planet, would fhine with lefs than the 180th part of its prefent light; and may we not conclude, that our new fatellites would be of a very confiderable brightnefs if they were brought fo near as the orbit of Jupiter, and thus appeared

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180 times brighter than at prefent? Nay, this is only when we take both the planets at their mean diftance; for, in their oppofitions, a fatellite brought from the fuperior planet to the orbit of the inferior one, would reflect nearly 250 times the former light; from all which it is evident, that the Georgian fatellites muft be of a confiderable magnitude.

If we draw together the refults of the foregoing calculations into a fmall compafs, they will ftand as follows:

The firft fatellite revolves round the Georgian planet in 8 days 17 hours 1 minute and 19 feconds.

Its diftance is 33″.

And on the 19th of October, 1787, at 19 h. 11′ 28″, its pofition was 76° 43′ north-following the planet.

The fecond fatellite revolves round its primary planet in 13 days 11 hours 5 minutes and 1,5 feconds.

Its greateft diftance is 44″,23.

And on the 19th of October, 1787, its pofition at 17 h. 22′ 40″, was 76° 43′ north-following the planet.

Laft year its leaft diftance was 34″,35; but the orbit is fo inclined, that this meafure will change very confiderably in a few years, and by that alteration we fhall know which of the double quantities put down for the inclination and node of its orbit are to be ufed.

The orbit of the fecond fatellite is inclined to the ecliptic $\left\{\begin{matrix} 99^\circ & 43' & 53{,}3'' \\ 81 & 6 & 4{,}4 \end{matrix}\right\}$.

Its afcending node is in $\left\{\begin{matrix} \text{18 degrees of Virgo} \\ \text{6 degrees of Sagittarius} \end{matrix}\right\}$.

When the planet paffes the meridian, being in the node of this fatellite, the northern part of its orbit will be turned towards the $\left\{\begin{matrix} \text{Eaft} \\ \text{Weft} \end{matrix}\right\}$.

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The ſituation of the orbit of the firſt ſatellite does not ſeem to differ materially from that of the ſecond.

We ſhall have eclipſes of theſe ſatellites about the year $\left\{\begin{matrix}1799\\1818\end{matrix}\right\}$, when they will appear to aſcend through the ſhadow of the planet almoſt in a perpendicular direction to the ecliptic.

The ſatellites of the Georgian planet are probably not leſs than thoſe of Jupiter.

The diameter of the new planet is 34217 miles.

The ſame diameter ſeen from the earth, at its mean diſtance, is 3″,90554.

From the ſun, at the mean diſtance of the earth, 1′ 14″,5246.

Compared to that of the earth as 4,31769 to 1.

This planet in bulk is 80,49256 times as large as the earth.

Its denſity as ,220401 to 1.

Its quantity of matter 17,740612 to 1.

And heavy bodies fall on its ſurface 18 feet 8 inches in one ſecond of time.

W. HERSCHEL.

Slough, March 1, 1788.

Fig. 1.

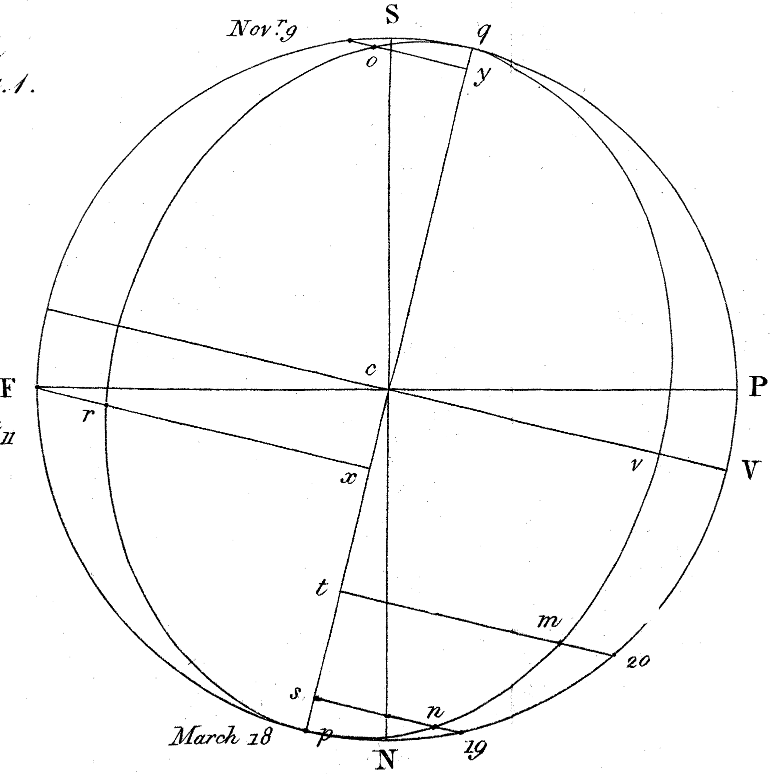


Fig. 2.

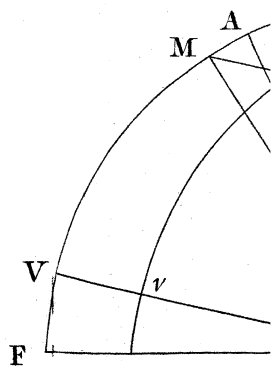


Fig. 3.

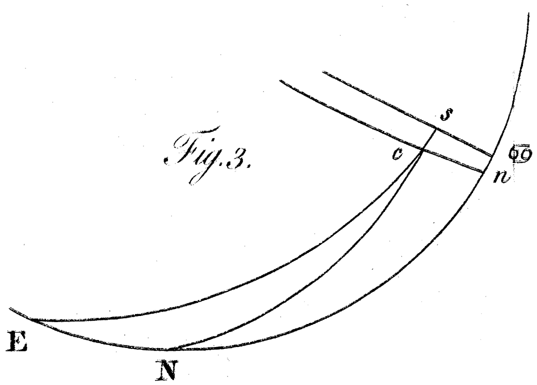
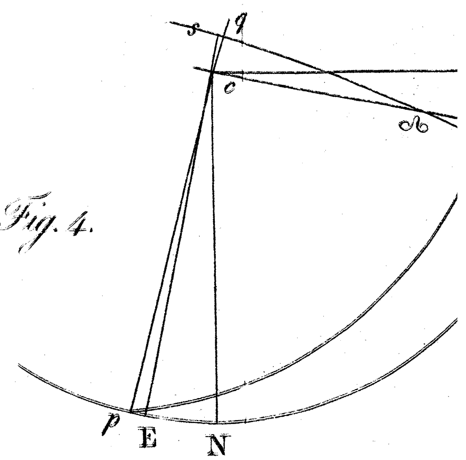
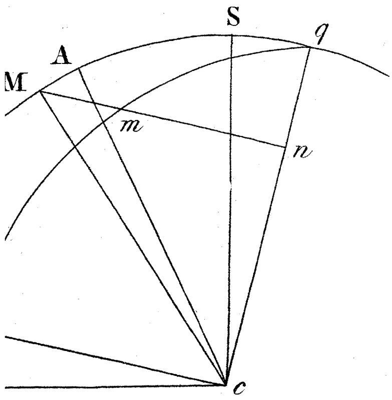
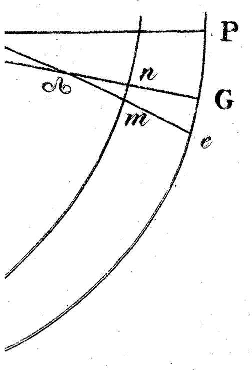


Fig. 4.



2.





Basire Sc.

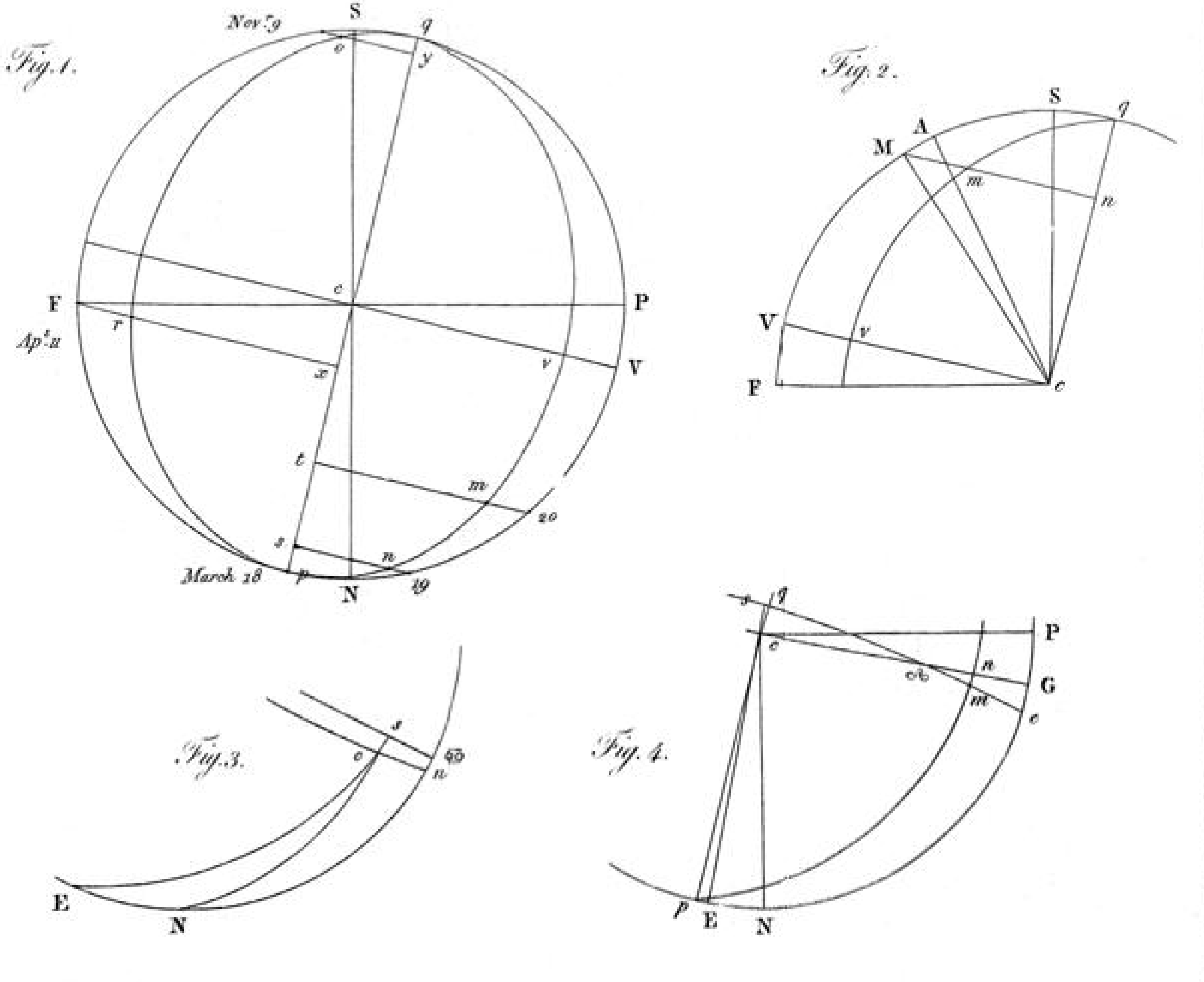


Fig. 1.
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Fig. 2.
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Fig. 3.
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Fig. 4.
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Basire Sc.